AD-A231 121

REPORT DOCUMENTATION PAGE

Form Approved
OMB No 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503

1. Agency Use Only *(Leave blank)*

2. Report Date.
1990

3. Report Type and Dates Covered.
Proceedings

4. Title and Subtitle.
The Oceanic Cloudy Atmosphere: Measurement Requirements and Solution Options

5. Funding Numbers.
Program Element No 62122N
Project No RR22-M51
Task No TASK 5
Accession No DN658755

6. Author(s).
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7. Performing Organization Name(s) and Address(es).
Naval Environmental Prediction Research Facility
Monterey, CA 93943-5006

8. Performing Organization Report Number.
PR 90:016:442

9. Sponsoring/Monitoring Agency Name(s) and Address(es).
Naval Air Development Center
Warminster, PA 18974-5000

DTIC
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JAN 17 1991
S B D

10. Sponsoring/Monitoring Agency Report Number.
PR 90:016:442

11. Supplementary Notes.
CIDOS
*Continued on next page

12a. Distribution/Availability Statement.
Approved for public release; distribution is unlimited.

cloud cover in an ocean environment

12b. Distribution Code.

13. Abstract *(Maximum 200 words)*.
The cloudy oceanic atmosphere influences warfare in a many ~~variety~~ of favorable and unfavorable ways. In this paper we presents the results of a quantitative evaluation of the effects of clouds and other atmospheric parameters on naval warfare areas and considers the use of a microwave system as deployed from airborne platforms to measure the desired parameters. The quantitative analysis scheme consists of development of a matrix with rows of cloud and other atmospheric environmental parameters and columns of naval warfare areas. Each matrix element was assigned a numerical weight according to the perceived importance of its associated parameter to the particular warfare area. Summing along rows produced a numerical value which is related to the multiple warfare importance of the particular environmental element. Summing down a given warfare column resulted in a numerical value related to the sensitivity of a single warfare area to the atmospheric environment in general. The study required development of an appropriate list of environmental parameters and a knowledge of the accuracy and resolution to which each parameter should be known. The parameter and requirements list was developed from a variety of naval and DOD requirements documents and interviews with Navy Code 1800 Oceanographic Officers. In the absence of specific requirements specifications, the judgment of the authors and that of Navy Code 1800 Oceanographic Officers was used to provide the input. All warfare areas were found to be significantly influenced by at least some atmospheric phenomena, with anti-air, anti-surface ship, and strike warfare being the most sensitive.
Measurement of the oceanic cloud environment to the highest detail desired by naval afloat activity can only be accomplished by a combination of surface, airborne, and satellite remote sensors. Both active and passive microwave systems are discussed.

14. Subject Terms.
(U) Hale; (U) UAV

15. Number of Pages.
14

16. Price Code.

17. Security Classification of Report.	18. Security Classification of This Page.	19. Security Classification of Abstract.	20. Limitation of Abstract.
Unclassified	Unclassified	Unclassified	SAR

A

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Accession For	
NTIS GRA&I	☑
DTIC TAB	☐
Unannounced	☐
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Availability Codes	
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A-1	

THE OCEANIC CLOUDY ATMOSPHERE: MEASUREMENT REQUIREMENTS AND SOLUTION OPTIONS

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ABSTRACT

The cloudy oceanic atmosphere influences warfare in a variety of favorable and unfavorable ways. In this paper we present the results of a quantitative evaluation of the effects of clouds and other atmospheric parameters on naval warfare areas and consider the use of microwave systems as deployed from airborne platforms to measure the desired parameters. The quantitative analysis scheme consists of development of a matrix with rows of cloud and other atmospheric environmental parameters and columns of naval warfare areas. Each matrix element was assigned a numerical weight according to the perceived importance of its associated parameter to the particular warfare area. Summing along rows produced a numerical value which is related to the multiple warfare importance of the particular environmental element. Summing down a given warfare column resulted in a numerical value related to the sensitivity of a single warfare area to the atmospheric environment in general. The study required development of an appropriate list of environmental parameters and a knowledge of the accuracy and resolution to which each parameter should be known. The parameter and requirements list was developed from a variety of naval and DoD requirements documents and interviews with Navy Code 1800 Oceanographic Officers. In the absence of specific requirements specifications, the judgment of the authors and that of Navy Code 1800 Oceanographic Officers was used to provide the input. All warfare areas were found to be significantly influenced by at least some atmospheric phenomena, with anti-air, anti-surface ship, and strike warfare being the most sensitive.

Measurement of the oceanic cloud environment to the highest detail desired by naval afloat activity can only be accomplished by a combination of surface, airborne, and satellite remote sensors. Both active and passive microwave systems are appropriate and will be briefly discussed in terms of their ability to observe the needed cloud parameters as well as other atmospheric parameters of interest.

1. INTRODUCTION

The efficacy of warfare is often influenced by clouds. The effects can be both positive and negative and apply to a variety of operational situations, weapons and search systems. Cloud types of importance range from fog at the surface to optically thin cirrus in the upper troposphere. To observe clouds on a global basis, satellite-derived high resolution visible, infrared, and microwave data are routinely processed into cloud and moisture analysis products. With respect to naval warfare it is of interest to assess the effects of clouds on warfare activity as a function of cloud characteristic and specific warfare area. In addition, it is important to consider the

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relative importance of clouds with respect to other environmental parameters which influence warfare activities.

In this paper, we employ a quantitative approach to evaluate the relative role of clouds and other atmospheric parameters in terms of their effect on a particular naval warfare area and as a function of multiple warfare areas. These results are adapted from a preliminary study for the design of airborne atmosphere, ocean, and geodetic environmental measurement systems supporting naval warfare activities (Ross, 1989).

2. ANALYSIS METHODOLOGY

In support of the requirements analysis study, reports listed in Table 1 were used to identify specific environmental parameters and, when available, the accuracy, and resolution requirements associated with measurement or prediction of the variable.

TABLE 1. REFERENCES

(1) MILITARY REQUIREMENTS FOR DEFENSE ENVIRONMENTAL SATELLITES. Joint Chiefs of Staff. 1986. Memorandum.

(2) REPORT ON ENVIRONMENTAL AND MC&G REQUIREMENTS FOR ANTI-SUBMARINE WARFARE SYSTEMS. Warfare System Architecture and Engineering Directorate, Space and Naval Warfare Systems Command. 1988.

(3) REPORT ON ENVIRONMENTAL REQUIREMENTS FOR THE BATTLE FORCE INFORMATION MANAGEMENT SYSTEM. Warfare System Architecture and Engineering Directorate, Space and Naval Warfare Systems Command. 1987.

(4) ENVIRONMENTAL SPACE SYSTEMS REQUIREMENTS ANALYSIS. Naval Space System Command. 1988. ST Systems Corp., Defense Analysis Div., Vienna, VA 22180.

(5) QUO VADIS II: LONG RANGE R&D PLAN FOR ENVIRONMENTAL SUPPORT TO NAVY WEAPONS, SENSORS, & PLATFORMS, 1990-2040. NORDA, Code 115. 1988 (DRAFT).

(6) ENVIRONMENTAL CRITICAL VALUES FOR MILITARY OPERATIONS. 1987. Naval Western Oceanography Center, Pearl Harbor, HI.

(7) NAVY SPACE OCEANOGRAPHY SCIENCE WORKING GROUP: OCEANOGRAPHY TEAM REPORT (DRAFT). 1987. NORDA, J. Mitchell, Ed.

(8) CATALOG OF PRODUCTS. 1988. Defense Mapping Agency. Washington, D.C. 20315-0010

(9) DOD UAV JOINT PROGRAM MASTER PLAN (DRAFT). 1989. UAV Joint Program Office, Naval Air Systems Command.

(10) COMNAVOCEANCOM METEOROLOGY MASTER PLAN ---FY92. May, 1989. Commander, Naval Oceanography Command, Stennis Space Center, MS.

The analysis approach consisted of:

* designation of appropriate environmental parameters,

* specification of the accuracy and spatial and temporal resolution at which the parameter needs to be known, and

* evaluation of each parameter as to its relative importance to specific warfare areas.

To perform the analysis, a quantitative procedure was used in an attempt to reduce the inherently subjective nature of requirements analysis and to establish an estimate of the relative importance of a given parameter. The details of the numerical approach will be described in Section 2.2.

In examining the references of Table 1 it was found that each environmental parameter actually has a range of accuracy and spatial and temporal resolution requirements which varied with (and within) a given warfare area. In general, the requirements were not quantitative, were often poorly documented, and many appeared highly subjective and out of date. Design of an instrument or system for measurement of the environment or development of a Tactical Decision Aid (TDA) analysis product must not be so constrained as to preclude further consideration of TDA or measurement system development. On the other hand, an inappropriately loose specification could result in a useless measurement or prediction product. Moreover, it is evident that most specifications of accuracies, resolution, etc., are necessarily subjective and many are highly time limited. Herein, an attempt at "organized subjectivity" is used to identify parameters, the accuracy and resolution to which they must be known, and their relative priority to the conduct of naval warfare.

To provide for a broad range of warfare requirements and to impart an element of "timelessness" to the analysis, a minimum and a desired accuracy and resolution (horizontal, vertical, and temporal) is specified for each parameter. This range is intended to cover the requirements of the majority of weapons systems and operational needs of all warfare areas. It is implicit that refinements to the accuracy and resolution ranges are needed as technology advances and warfare system needs change. In addition, when the needs of specific weapons systems or operational requirements are being considered, these values should be reviewed and adjusted as required.

2.1 ENVIRONMENTAL PARAMETERS

Each environmental parameter considered here is first stated in terms of its generic nomenclature (e.g., "clouds"). When appropriate, it is then broken into sub-elements. This was done since a given warfare area may place more emphasis on a specific detail than would another warfare area. Clouds are a good example; many ASW assets require knowledge of cloud base and fog, whereas AAW users will be concerned with clouds at all levels. This approach has the effect of weighting a given generic area and must be taken into consideration in interpretation of the results. An alternate approach would be to average the values associated with each generic element and then arbitrarily weight the result. For this report we have chosen the former approach since it has the effect of weighting the parameters in the least subjective manner.

The atmospheric environmental parameters considered here and their accuracy, spatial, and temporal resolution requirements are shown in Table 2. The values shown were extracted from the publications listed in Table 1, or, if not available, were based upon the judgment of the authors. For example, reference (1) presented detailed and quantitative requirements for satellite measurement of a wide variety of atmospheric parameters. Unfortunately, documents such as reference (2) address the environment in terms of criticality rather than quantitative measurements and as such do not provide needed specifications. All values of Table 2 were reviewed and adjusted, when appropriate, by the Naval Oceanography Command Detachment (NOCD) at the U. S. Naval Postgraduate School, LCDR. K. Curry, Officer in Charge.

TABLE 2. ATMOSPHERE ACCURACY AND SPATIAL AND TEMPORAL RESOLUTION REQUIREMENTS

PARAMETER	ACCURACY MINIMUM	ACCURACY DESIRED	HORIZONTAL RESOLUTION MINIMUM	HORIZONTAL RESOLUTION DESIRED	VERTICAL RESOLUTION MINIMUM	VERTICAL RESOLUTION DESIRED	TEMPORAL RESOLUTION MINIMUM	TEMPORAL RESOLUTION DESIRED
CLOUD								
% COVERAGE	10 %	1 %	4 KM	0.1 KM	N/A	N/A	3 HR	.1 HR
TYPE	1/6 TYPE	1/18 TYPE	4 KM	0.1 KM	N/A	N/A	3 HR	.1 HR
LEVEL	0.3 KM	0.03 KM	4 KM	0.1 KM	0.3 KM	0.03 KM	3 HR	.1 HR
THICKNESS	1 KM	0.03 KM	4 KM	0.1 KM	0.3 KM	0.03 KM	3 HR	.1 HR
ALBEDO	5 %	0.5 %	4 KM	0.1 KM	N/A	N/A	3 HR	.1 HR
BASE	0.25 KM	0.03 KM	4 KM	0.1 KM	0.3 KM	0.03 KM	3 HR	.1 HR
TOPS	0.3 KM	0.03 KM	4 KM	0.1 KM	0.3 KM	0.03 KM	3 HR	.1 HR
FOG	Y/N	1/3 TYPES	4 KM	0.1 KM	0.3 KM	0.03 KM	3 HR	.1 HR
WINDSPEED								
SURFACE	2.5 M/S	1 M/S	25 KM	5 KM	1 KM	0.03 KM	12 HR	1 HR
UPPER LEVEL	5 M/S	1 M/S	25 KM	5 KM	1 KM	1 KM	12 HR	1 HR
PROFILE	5 M/S	1 M/S	25 KM	5 KM	0.3 KM	0.03 KM	12 HR	1 HR
TURB (U'W')	TBD M2/S2	TBD	25 KM	1 KM	TBD	TBD	12 HR	1 HR
REGION > 15 M/S	5 M/S	2 M/S	25 KM	1 KM	N/A	N/A	12 HR	1 HR
WIND DIRECTION								
SURFACE	30 DEG.	5 DEG.	25 KM	5 KM	1 KM	0.03 KM	3 HR	1 HR
UPPER LEVEL	30 DEG.	5 DEG.	25 KM	5 KM	4 LEVELS	0.3 KM	3 HR	1 HR
PROFILE	30 DEG.	5 DEG.	25 KM	5 KM	1 KM	0.1 KM	3 HR	1 HR
PRESSURE								
PROFILE	5 MB	1 MB	50 KM	1 KM	1 KM	10 M	3 HR	< 1 HR
SURFACE	5 MB	1 MB	50 KM	1 KM	N/A	N/A	3 HR	< 1 HR
PRECIPITATION								
RATE	4 MM/HR	0.2 MM/HR	4 KM	1 KM	1 KM	0.10 KM	3 HR	1 HR
PSD	TBD	TBD	TBD	TBD	TBD	TBD	3 HR	1 HR
HAIL/NO HAIL	YES/NO	TBD	4 KM	1 KM	TBD	TBD	3 HR	1 HR
TEMPERATURE								
SURFACE	1 C	0.1 C	4 KM	1 KM	N/A	N/A	12 HR	1 HR
PROFILE	1 C	0.1 C	100 KM	1 KM	100 M	1 M	12 HR	1 HR
GRAD. INFLEC.	100 M	0.1 M	4 KM	0.5 KM	0.3 KM	0.01 KM	12 HR	1 HR
MOISTURE								
SUR. HUMIDITY	10 %	2 %	100 KM	10 KM	N/A	N/A	12 HR	3 HR
INT. L. H2O	1 KG/M2	0.1 KG/M2	4 KM	1 KM	N/A	N/A	12 HR	1 HR
M PROFILE	2.5 G/M3	.1 G/M3	100 KM	1 KM	0.6 KM	0.01 KM	12 HR	1 HR
GRAD. INFLEC.	100 M	1 M	4 KM	0.5 KM	100 M	1 M	12 HR	1 HR
ICING								
LEVEL	0.5 KM	.1 KM	4 KM	1 KM	5 KM	1 KM	12 HR	1 HR
STRENGTH	1 OF 3 LEVELS	TBD	4 KM	1 KM	N/A	N/A	12 HR	1 HR
VISIBILITY								
SURFACE	5 KM	0.5 KM	100 KM	1 KM	3 KM	0.25 KM	12 HR	0.25 HR
SLANT PATH	5 KM	0.5 KM	100 KM	1 KM	5 KM	1 KM	12 HR	0.25 HR
AEROSOLS								
SURF EXTINC.	20 %	5 %	100 KM	1 KM	3 KM	0.25 KM	12 HR	0.25 HR
SLANT EXTINC.	20 %	5 %	100 KM	1 KM	5 KM	1 KM	12 HR	0.25 HR
ELECTRICITY								
LIGHTNING	MAYBE	YES/NO	TBD	TBD	TBD	TBD	TBD	TBD
REFRACTIVE INDEX								
GRADIENT	100 N/KM	1 N/KM	250 KM	1 KM	100 M	3 M	12 HR	1 HR
THICKNESS	0.1 KM	0.01 KM	250 KM	1 KM	100 M	1 M	12 HR	1 HR

UNITS

C	DEGREES CENTIGRADE	M	METER
GRAD INFLEC.	GRADIENT INFLECTION POINT	M/S	METERS PER SECOND
INT	INTEGRATED	M2/S2	METERS SQUARED PER SECOND SQUARED
KM	KILOMETERS	N	RADIO REFRACTIVE INDEX
KM^{-1}	EXTINCTION UNITS (1/KM)	PSD	PARTICLE SIZE DISTRIBUTION
KG/M2	KILOGRAMS PER SQ. METER	NOTE:	RATIOS INDICATED SUCH AS 1/6 MEAN ONE OF SIX CATEGORIES; REFRACTIVE INDEX THICKNESS PARAMETER IMPLIES HEIGHT SPECIFICATION

An important feature of Table 2 is that the values specified are intended to meet <u>present</u> as well as projected <u>future</u> needs, modified by practical considerations. For example, wind speed is specified as desirable at an accuracy of 1 m/s. In fact, higher accuracy may sometimes be desirable but, when such measurements are impractical to achieve and the more stringent need is not yet established, the more conservative value is used.

2.2 ENVIRONMENTAL WARFARE REQUIREMENTS ANALYSIS

To estimate the relative importance of the environmental parameters, each was considered with respect to individual warfare areas. Table 3 lists the warfare areas considered here.

TABLE 3. WARFARE AREAS

(1) Anti-Submarine Warfare (ASW)
(2) Anti-Air Warfare (AAW)
(3) Anti-Surface Ship Warfare (ASUW)
(4) Amphibious Warfare (AMW)
(5) Strike Warfare(STW)
(6) Mine Warfare (MIW)
(7) Electronic Warfare (ELW)
(8) Command, Control and Communications (C^3)
(9) Intelligence (INT)
(10) Naval Special Warfare (NSW)
(11) Logistics (LOG)
(12) Mobility (MOB)
(13) Construction (CON)
(14) Tactical Environmental Support System (TESS)

The TESS is a facility which receives environmental data and numerical weather products and prepares Tactical Decision Aids (TDAs) for transmission to the user. As such, it is not a warfare area. However, since it represents a major user of environmental data, it is given equal consideration.

After specification of accuracy and spatial/temporal resolution the relative importance of each environmental requirement as a function of warfare area must be established. This was done by using a quantitative weighting scheme wherein environmental elements are organized in rows and warfare areas as columns in a Lotus 123 spreadsheet in a manner similar to that of reference 4 of Table 1. Each environmental parameter is assigned a number from 0 to 7 for each warfare area according to the following criteria:

VALUE	CRITERIA
0	NOT IMPORTANT
1	UNKNOWN IMPORTANCE
2	USED IF AVAILABLE AT MINIMUM REQUIREMENT LEVEL
3	USED IF AVAILABLE AT DESIRED REQUIREMENT LEVEL
4	DESIRABLE IF AVAILABLE AT MINIMUM REQUIREMENT LEVEL
5	DESIRABLE IF AVAILABLE AT DESIRED REQUIREMENT LEVEL
6	MANDATORY AT MINIMUM REQUIREMENT LEVEL
7	MANDATORY AT (USUALLY) DESIRED REQUIREMENT LEVEL

For example, cloud percent coverage is of moderate importance to ASW since in general it impacts only aircraft or helicopter assets. For AAW, however, both defensive and offensive weapons systems may be impacted to a level which may be vital to survivability of a ship or Battle Group. Thus, the requirement for observing clouds is very high for AAW and is most useful at a very high accuracy and spatial and temporal resolution. On the other hand, ASW assets are mildly sensitive to cloud percent coverage and somewhat more sensitive to the height of cloud base. Accordingly, the ASW requirement is rated 4 for percent coverage, and 5 for cloud base information, while AAW receives a 7 and 6 rating for percent cloud and cloud base respectively. The 2 rating is assigned when even a minimum accuracy or resolution is useful. The 3 rating is assigned when the parameter is useful, but only if available at the more stringent accuracy or resolution. The use of 6 and 7 levels were reserved for those categories considered to be dynamic and appropriate for airborne measurement. The assigning of values was accomplished using the references of Table 1 as a guide and the experience of the authors and Code 1800 officers. In summary, the quantitative value assigned here is an interpretation of the requirements as discerned from the references of Table 1.

The use of a numerical valuation scheme for prioritizing environmental parameters would be strengthened by a continuing official review procedure to sanction and maintain control of environmental requirements. This procedural requirement may be addressed by the Top Level Warfare Requirement document and its associated Oceanography Master Plan currently under development by the Oceanographer of the Navy. The requirements definition process should include definitive and quantitative specification of measurement needs as determined by weapons system program managers and operational planners for each warfare area.

3. SINGLE AND MULTIPLE-WARFARE REQUIREMENTS ANALYSIS

3.1 SINGLE WARFARE REQUIREMENTS ANALYSIS

The relative importance of the atmosphere for each warfare area as established by this analysis is shown in Table 4. This table contains a column for each warfare area including TESS. By summing down each column (Warfare Area) of Table 4, the Single Warfare Requirement Index (SWRI) is obtained. This index provides a basis for comparison of the relative importance of the cumulative atmosphere parameters for each warfare area.

Figure 1 is a bar graph representation of the SWRI for each warfare area. AAW, ASUW, STW, and TESS are seen to be highly dependent upon the atmospheric environmental parameters used and others are significantly dependent. It should be noted that some warfare areas are particularly sensitive to only one or two parameters and that this sensitivity would be more apparent if bar graphs were created for each warfare area. However, the goal here is to achieve a higher level view of the importance of the atmosphere to warfare in general rather than the highlighting of particular warfare results.

3.2 MULTIPLE WARFARE REQUIREMENTS ANALYSIS

The relative multiple warfare importance of a specific environmental parameter is determined by summing across a single parameter row of Table 4. Figure 2 presents a bar graph representation of the Multiple Warfare Requirement Index (MWRI) for each environmental parameter. The cumulative value for each generic area is calculated and assigned to the generic title which is labeled in the figure. It can be seen from Fig. 2 that the atmospheric parameter of broadest significance to naval warfare in general is clouds. This is due in part to the arbitrary breakdown of clouds into a number of sub-elements. An environmental parameter impacts warfare either through its complexity or through its impact on critical warfare areas. By division of clouds, for example, into a number of sub-elements we have weighted this area in as natural a manner as possible. Considered collectively, clouds, moisture, and windspeed have the broadest requirement base. Refractive index is rated slightly lower than moisture since it is less important across multiple warfare areas. Its importance to AAW, and ASUW, however, must be recognized and assignment of additional priorities to specific parameters is one solution to this problem. Nevertheless, it should be noted that clouds would still rate highly. An alternative to the cumulative approach would be to average the values as a function of warfare area. This approach, however, treats less complex environmental areas as equal to more complex areas and priority parameters are less obvious.

TABLE 4. ATMOSPHERE: SINGLE AND MULTIPLE-WARFARE REQUIREMENT ANALYSIS

PARAMETER	#	ASW	AAW	ASUW	AMW	STW	MIW	ELW	C3	INT	NSW	LOG	MOB	CON	TESS		Multiple Warfare Requirement Index MWRI
CLOUD	1															Sum:	405
% COVERAGE	2	4	7	6	5	7	4	4	4	3	3	4	5	4	6		66
TYPE	3	3	5	5	5	5	4	4	4	3	1	3	3	3	5		53
THICKNESS	4	3	7	7	4	7	4	4	4	3	1	5	5	3	5		62
* ALBEDO	5	2	4	5	4	4	1	1	1	3	1	0	0	0	6		32
BASE	6	5	6	7	5	7	5	5	5	3	6	5	5	0	6		70
* TOPS	7	3	6	7	4	7	2	2	2	3	1	1	1	0	7		46
FOG	8	4	6	7	5	7	6	6	6	3	6	5	5	4	6		76
TEMPERATURE	9															Sum:	144
SURFACE	10	2	4	4	3	4	4	1	2	2	4	2	2	4	4		42
PROFILE	11	2	6	6	1	6	3	5	3	2	3	1	1	1	5		45
INFLECTION POINT	12	4	6	7	4	6	4	5	5	5	3	1	1	0	6		57
MOISTURE	13															Sum:	182
SURFACE RH	14	4	5	5	3	5	1	1	1	1	3	1	1	2	5		38
INTEGRATED LWC	15	2	5	4	3	5	1	1	1	1	3	0	0	0	5		31
PROFILE	16	3	6	6	4	7	4	5	4	5	3	1	1	0	6		55
INFLECTION POINT	17	4	6	7	4	6	4	5	5	5	3	1	1	0	7		58
WINDSPEED	18															Sum:	258
SURFACE	19	5	5	6	4	6	4	1	2	1	5	4	4	5	5		57
UPPER LEVEL	20	2	5	6	3	5	5	1	1	1	3	5	5	0	4		46
PROFILE	21	4	5	6	4	6	3	1	2	1	3	3	1	0	3		42
TURBULENCE (U'W')	22	2	5	5	3	5	5	1	1	1	3	5	5	0	4		45
U REGION > 15 M/S	23	5	5	6	5	6	5	1	5	5	5	5	6	5	4		68
WIND DIRECTION	24															Sum:	151
SURFACE	25	3	7	6	5	7	2	1	1	2	5	4	4	2	7		56
UPPER LEVEL	26	3	7	6	4	7	3	1	1	2	3	1	1	0	7		46
PROFILE	27	3	7	5	5	6	3	1	1	2	3	3	3	1	6		49
PRECIPITATION	28															Sum:	134
RAIN RATE	29	4	6	6	4	6	4	5	6	4	2	3	2	3	5		60
RAIN PSD	30	1	5	6	1	5	0	5	4	2	2	1	2	0	5		39
HAIL/NO HAIL	31	2	2	2	2	4	4	1	3	2	3	3	2	2	3		35
VISIBILITY	32															Sum:	120
SURFACE	33	4	6	6	6	6	5	0	4	3	5	6	6	1	5		63
SLANT	34	5	6	6	5	6	5	0	4	3	2	4	4	2	5		57
AEROSOLS	35															Sum:	76
SURF. EXTINCTION	36	3	5	5	3	5	2	0	3	3	2	1	1	1	4		38
SLANT EXTINCTION	37	3	5	5	3	5	2	0	3	3	2	1	1	1	4		38
PRESSURE	38															Sum:	45
PROFILE	39	0	2	3	0	3	0	0	2	1	2	1	1	1	4		20
SURFACE	40	0	2	3	3	5	0	0	2	1	2	1	1	1	4		25
ICING	41															Sum:	92
LEVEL	42	5	6	4	2	5	5	0	3	5	2	4	4	1	4		50
STRENGTH	43	5	5	4	2	5	5	0	2	2	3	3	0	1	5		42
ELEC. (LIGHTNING)	44	3	4	3	3	3	5	5	5	3	3	4	1	3	3	Sum:	48
REFRACTIVE INDEX	45															Sum:	135
EM DUCT GRADIENT	46	3	6	6	6	6	6	7	6	6	3	4	2	0	7		68
EM DUCT THICKNESS	47	3	6	6	6	6	6	7	6	6	3	4	1	0	7		67
Single Warfare Requirement Index	SWRI	113	191	194	133	201	126	87	114	101	107	100	88	51	184		1790

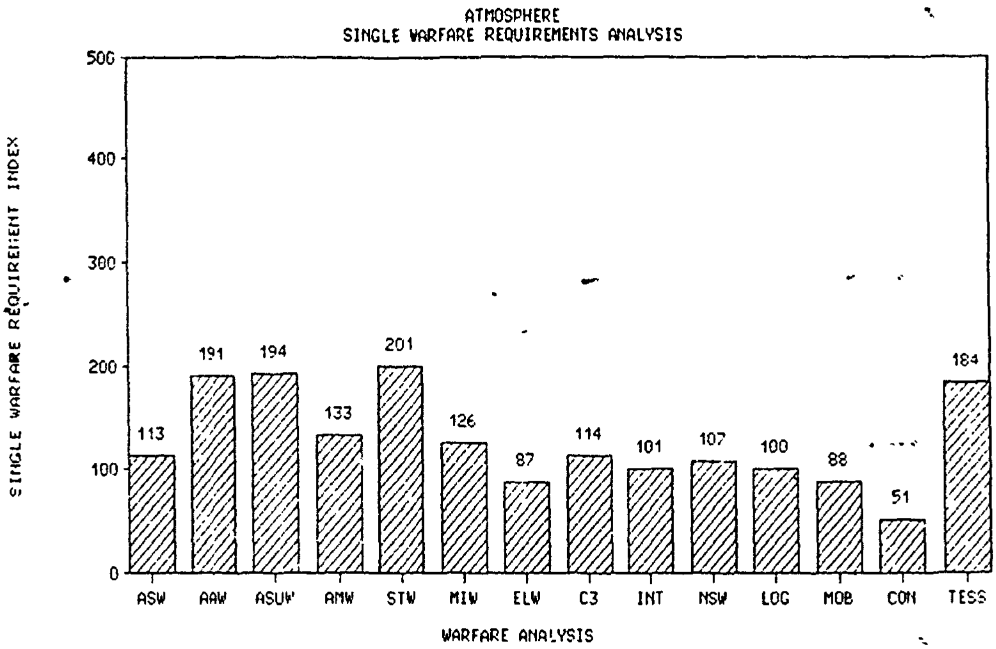

Figure 1. Atmosphere Single Warfare Requirements Analysis

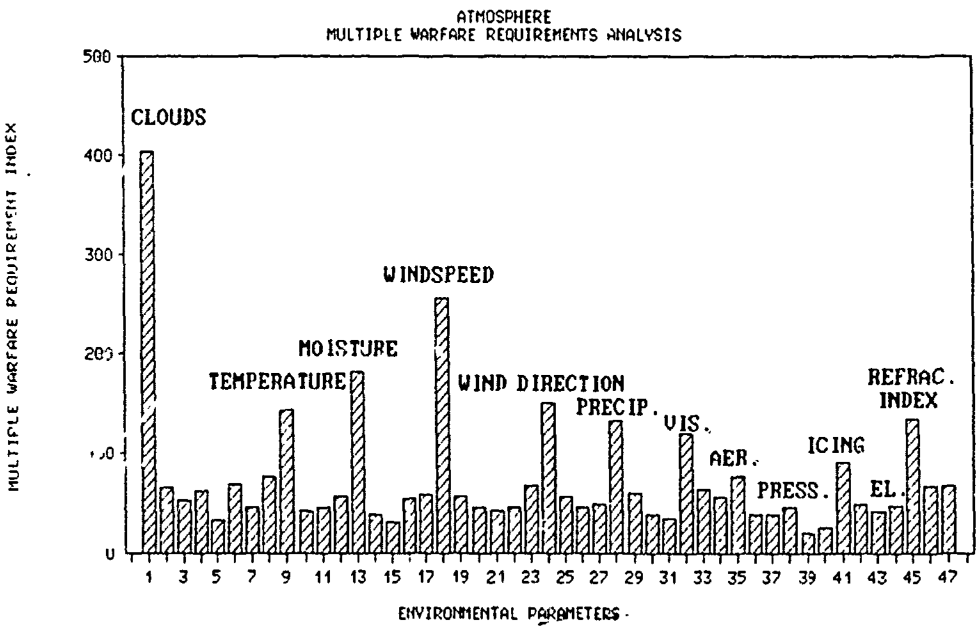

Figure 2. Atmosphere Multiple Warfare Requirements Analysis

4. CLOUD MEASUREMENT TECHNIQUES

A review of cloud measurement techniques is required in order to provide some insight on solution options. The weighting of Table 4 should be used to design the prototype system. Observation of many of the variables of Table 4 are required at field locations and at high resolution as well as on a global basis at lower resolution. Here, for the sake of brevity, we will only consider remote sensing techniques suitable for the field situation.

4.1 AIRBORNE AND SATELLITE MEASUREMENT POTENTIAL

The use of satellite systems in the visible, infrared, and passive microwave bands for observing clouds is well recognized. The major limitation to their use is associated with relatively limited spatial and (in northern latitudes) temporal resolution and the inability to reliably observe such cloud systems as high cirrus, stratus in arctic regions, multi-level systems, and the height of cloud base. Use of satellites to classify and specify cloud type, base, and thickness has improved due to increased availability of additional spectral bands and resolution. This situation will improve in the 1990's with the launch of GOES NEXT which will provide multi-spectral data as frequently as every 10 minutes. Improved polar orbiting satellites as part of the DoD and NASA programs (DMSP and EOS) will also provide environmental measurements with improved spectral and spatial resolution.

Many of the satellite measurement systems are appropriate for airborne use when high temporal and spatial resolution is a requirement. In support of DoD warfare requirements, airborne platforms can provide important data in both denied as well as neutral areas. For the denied areas it may be inappropriate to utilize certain active systems. However, for platforms in the stratosphere we note that complete stealth is unlikely. Therefore, use of downward looking visible and IR, Lidar, and mm wave microwave profilers may be appropriate for use. Assuming this is the case, we can address the more stringent requirements of observing cloud parameters from a system which includes high altitude airborne platforms as well as satellites.

Listed below are the requirements for observing a subset of cloud characteristics; the "desired" classification as established in Table 2 is shown.

DESIRED CLOUD MEASUREMENT CAPABILITY

PARAMETER	ACCURACY	HORIZONTAL RESOLUTION	VERTICAL RESOLUTION	TEMPORAL RESOLUTION
CLOUD				
% COVERAGE	1 %	0.1 KM	N/A	0.1 HR
TYPE	1 OF 18 TYPES	0.1 KM	N/A	0.1 HR
THICKNESS	0.03 KM	0.1 KM	0.03 KM	0.1 HR
ALBEDO	0.5 %	0.1 KM	N/A	0.1 HR
BASE	0.03 KM	0.1 KM	0.03 KM	0.1 HR
TOPS	0.03 KM	0.1 KM	0.03 KM	0.1 HR
FOG	1 OF 3 TYPES	0.1 KM	0.03 KM	0.1 HR

The requirement for virtually real time knowledge of cloud conditions is very stringent. Nevertheless, such a capability was found to be desirable. A geostationary satellite can meet the real time requirement for many parameters at low and mid-latitudes, but cannot meet the resolution requirements. Similarly, a polar orbiting satellite can be designed to meet the accuracy and horizontal resolution requirements, but cannot meet many of the vertical or temporal requirements. The use of a high altitude airborne platform with extended range capability to provide a capability of loitering over priority areas could meet many of the above requirements. Such an aircraft concept is described by Bauilinger and Page (1989) and would be invaluable in many military operational scenarios short of full scale warfare. The recent Iranian alert situation is a good example of a high priority military requirement. Civilian utilization of such an aircraft could include high altitude atmospheric research and monitoring, tropical and extra-tropical storm monitoring, topographic mapping, snow and ground moisture monitoring, radio and television relay, and search and rescue.

As an exercise in design of a system to meet only the cloud measurement requirements, the assumption is made that a suitable airborne platform is available and capable of sufficient pay-load and endurance to accommodate a suite of environmental instruments. It is also noted that in addition to the cloud parameters themselves, information is needed on other aspects of the environment, such as the profile of wind speed and direction, air temperature, liquid water content, particle size distribution, visibility, and precipitation rate. Table 5 presents a quantitative analysis of the capability of different sensing approaches to the measurement of the cloudy environment. In this case, the value assigned to each parameter varies from 0 to 3, as described in the key below the table. From this table, we find that an active microwave and a visible and infrared system can provide the majority of the needed measurables.

TABLE 5. ATMOSPHERE: SATELLITE/AIRBORNE MEASUREMENT POTENTIAL

PARAMETER	LASER	ACTIVE MICROWAVE	PASSIVE MICROWAVE	VISIBLE/IR
CLOUD				
% COVERAGE	1	0	2	3
TYPE	2	2	2	3
THICKNESS	2	3	0	1
ALBEDO	3	1	2	3
BASE	2	3	0	1
TOPS	3	3	0	3
FOG	2	1	0	3
TEMPERATURE				
SURFACE	3	0	2	2
PROFILE	3	0	3	3
INFLECTION PT.	3	0	3	2
MOISTURE				
SURFACE RH	1	1	1	0
INTEGRATED LWC	1	1	3	0
PROFILE	2	1	3	0
INFLECTION PT.	2	3	3	0
WINDSPEED				
SURFACE	2	3	3	0
UPPER LEVEL	2	3	0	2
PROFILE	2	2	0	0
TURBULENCE (U'W')	2	3	0	0
REGION > 15 M/S	2	3	3	0
WIND DIRECTION				
SURFACE	2	3	0	0
UPPER LEVEL	2	3	0	0
PROFILE	2	3	0	0
PRECIPITATION				
RAIN RATE	[illegible]	3	3	3
RAIN PSD	0	2	1	0
HAIL/NO HAIL	0	1	1	3

RATING	
0	Not possible to measure
1	Requires additional data or development
2	Potential exists; accuracy, additional development, or weather limitations must be considered
3	Demonstrated capability
N/A	Not applicable

4.2 Potential Cloudy Environment Measurement System

A visible/infrared scanner and a scanning Doppler radar profiler can provide most of the measurements indicated in Table 5. Visible and infrared scanners are commercially available and provide a known product. Therefore, it is only necessary to discuss briefly an appropriate radar configuration.

Pulsed Doppler radar has been used in recent years to observe cloud parameters. Biswas and Hobbs (1988) used 35 GHz to observe cloud base and height parameters of precipitation-free clouds. Lhermitte (1989) evaluated radar frequencies from 15 to 94 GHZ for cloud measurements and proposed a scanning 94 GHz system for satellite application. The choice of frequency was based upon size and weight limitations and availability of reliable hardware. Using the results of Lhermitte, Table 6 indicates the parameters of a Doppler radar system appropriate for an airborne platform which would be capable of detecting cloud top and base for clouds with minimum liquid water content of about .1 g/m^3 or a rain intensity of 10^{-3} mm/hr. The system would also be capable of detecting profiles of the u, v, and w components of the wind. Final specifications of a system would depend upon hardware and power limitations of the platform.

TABLE 6. 94 GHz Doppler Radar Characteristics

Frequency	94	GHz
Wavelength	3.2	mm
Peak power	1	kW
Average power	10	W
Pulse width	1	microsecond
PRF	2500	Hz
Antenna Diameter	1	m
Ant. Beamwidth	0.2	deg.
Footprint @ 20 km	64	m
Vertical Resolution	150	m
Rec. Noise	-100	dBm
Min. Det. radar return	-100	dBm cm-1
Minimum Det. dBZ	< -25	
Estimated power required	500	watts
Estimated weight	25	kg

4. CONCLUSIONS

A numerical weighting scheme has been used to analyze requirements for observing the atmospheric environment in support of naval warfare. This analysis suggested clouds have the broadest environmental impact on the various warfare areas. Observation of the clouds at the desired accuracy and resolution, however, cannot be accomplished with a single measurement system. To significantly improve present ability to meet the field observation requirements, a higher altitude long endurance airborne platform is needed. Such an aircraft equipped with a multi-spectral visible and infrared scanner and a scanning Doppler radar can provide many of the desired measurements. Addition of a lidar would provide additional data in thin clouds, and other valuable data in cloud free regions. The analysis here suggests a 94 or a 35 GHz Doppler radar system would provide the best microwave compromise depending upon the power and weight limitations of the aircraft. Existing studies at these frequencies suggest a field program to evaluate performance of a brassboard system and refine design criteria would be an appropriate next step.

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For the sake of brevity in production of this paper, many references which support conclusions or statements were omitted from the above text. They are included in this section for the convenience of the reader.

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KEY WORDS

ATMOSPHERE
ATMOSPHERIC MEASUREMENTS
CLOUDS
DOPPLER RADAR
ENVIRONMENTAL MEASUREMENTS REQUIREMENTS
HIGH ALTITUDE
LIDAR
SATELLITE
WEATHER MONITORING